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RESEARCH ARTICLE

Prevalence and risk factors of glomerular hyperfiltration in adults with type 2 diabetes: A population-based study

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Abstract

Aims: Glomerular hyperfiltration characterises the earliest stage of diabetic nephropathy and predicts adverse kidney and cardiovascular outcomes. We aimed to assess the prevalence and risk factors of glomerular hyperfiltration in a population-based contemporary cohort of individuals with type 2 diabetes (T2D).

Materials and Methods: The prevalence of unequivocal glomerular hyperfiltration (defined by an estimated glomerular filtration rate >120 mL/min/1.73 m^2) and its associated risk factors were identified in a cohort of 202,068 adult patients with T2D receiving specialist care in 2021–2022, whose center-aggregated data were automatically extracted from electronic medical records of 75 diabetes clinics in Italy.

Results: Glomerular hyperfiltration was identified in 1262 (0.6%) participants. The prevalence of glomerular hyperfiltration varied widely across centers (0%–3.4%) and correlated with mean center age, HbA_{1c}, body mass index (BMI), and low-density lipoprotein cholesterol. Patients in centers with high glomerular hyperfiltration prevalence (>0.8%) were more often men and had lower age and BMI, but more frequent albuminuria and worse glucose, lipid, and blood pressure control, compared with low-normal prevalence centers.

Conclusions: Unequivocal glomerular hyperfiltration can be identified in up to 3.4% of patients receiving up-to-date specialist diabetes care. Glomerular hyperfiltration prevalence varies across centers and substantially increases with suboptimal control of metabolic risk factors, which would require improved management to mitigate the negative health consequences of this pathological condition.

KEYWORDS

chronic kidney disease, epidemiology, glomerular hyperfiltration, real-world study, type 2 diabetes

[†]Deceased during the publication process.

1 | INTRODUCTION

Chronic kidney disease (CKD) associated with type 2 diabetes (T2D) is a leading cause of end-stage kidney disease worldwide, whose incidence is projected to increase over the next decades.[1] The preclinical stage of diabetic nephropathy is characterised by an abnormal elevation in glomerular filtration rate (GFR), defined as glomerular hyperfiltration, which can contribute to kidney damage progression and albuminuria by increasing capillary pressure and tensile stress.[2] Glomerular hyperfiltration has been associated with worse kidney[3–5] and cardiovascular outcomes[6,7] and increased cardiovascular and all-cause mortality,[5,8,9] which are only partly explained by its close association with poor glycaemic control, obesity, hypertension, and dyslipidemia.[2]

The prevalence of glomerular hyperfiltration and its associated risk factors in the general population of individuals with T2D remains unknown. In fact, the reported prevalence of glomerular hyperfiltration in these individuals varied greatly, from 6% to 73%, reflecting the high variability in diagnostic criteria and populations' characteristics.[10,11] Moreover, previous studies analysed relatively small cohorts and were mostly conducted more than 20 years ago, that is before the development of novel therapies and guidelines for the management of CKD risk factors.

To fill this knowledge gap, this large-scale study aimed to identify the prevalence of glomerular hyperfiltration in a contemporary cohort of patients with T2D across 75 diabetes centers in Italy, and to recognise the main risk factors associated with this pathological condition among established components of the metabolic syndrome.

2 | METHODS

2.1 | Data collection

Aggregate patient data were collected in 2022 from 75 secondary and tertiary referral diabetes clinics in Italy, which were evenly distributed across the four peninsular macroregions (North-West: $n = 21$ [28%], North-East: $n = 16$ [21%], Center: $n = 21$ [28%], and South: $n = 17$ [23%]). Patient inclusion criteria for data extraction were diagnosis of T2D, age >18 years, and at least one recorded access to the clinic within the 12 months prior to data extraction. Aggregated center data were automatically extracted from electronic medical records of each center using the 'Tool Pioneering Assessment' software (Smart Digital Clinic, Meteda), provided within an educational project approved by the National Agency for Regional Health Services (AGENAS, ECM:5310–329114). Data extracted from each center included center size and location, sex distribution, and the average and SD of patients' age, body mass index (BMI), HbA_{1c}, blood pressure, total and fractional cholesterol, and triglycerides. Collected data also included the proportion of patients in each center with an estimated glomerular filtration rate (eGFR) > 120 or <30 mL/min/1.73 m^2, albuminuria, longstanding diabetes (>5 years), obesity (BMI >30 kg/m^2), previous or active smoking habit, poor management of glucose (HbA_{1c} >7%), blood pressure (>140/90 mmHg), and low-density lipoprotein (LDL) cholesterol (LDL-c) (>100 mg/dL), as well as information about active pharmacological treatments. According to the Italian Medicines Agency det. 20/03/2008 on retrospective observational studies on anonymous data, preemptive approval by an ethics committee was not mandatory and the need for informed consent was waived given that aggregated center data were automatically collected and cannot be referred to specific individuals. The study was conducted in accordance with the 1964 Declaration of Helsinki and its later amendments.

2.2 | Definitions

Unequivocal glomerular hyperfiltration was defined as an eGFR > 120 mL/min/1.73 m^2 using the creatinine-based Chronic Kidney Disease Epidemiology Collaboration formula,[12] according to previous studies.[13,14] The 75th percentile of the frequency distribution curve of glomerular hyperfiltration prevalence across participating centers (0.8%) was used as a cut point to identify centers with a high prevalence of glomerular hyperfiltration.

2.3 | Statistical analysis

Given that patient data were aggregated by participating center, the unity of the analysis was the individual center. Continuous variables are reported as mean ± SE of inverse-variance weighted aggregated center data. Categorical variables are reported as mean ± SE of individual center proportions using the center size as weight. Group differences were tested by Student's t tests weighted by inverse variance or center size as appropriate. Correlations were tested using inverse-variance weighted Pearson correlation. Multivariable linear regression weighted for center size was used to identify the main determinants of glomerular hyperfiltration prevalence among standardised age, sex, BMI, HbA_{1c}, systolic blood pressure, LDL-c, and albuminuria. Exploratory analyses were performed including either the prevalence of longstanding diabetes (>5 years from diagnosis) or the prevalence of treatment with sodium-glucose cotransporter 2 (SGLT-2) inhibitors among model independent variables. Aggregated BMI data from 12 (16%) centers were excluded from analysis because of inappropriately high mean or SD values reflecting non-biologically sound outliers that could not be excluded at the patient level. Analyses were performed using JMP Pro software version 17 (SAS Institute) at a two-sided α level of 0.05.

3 | RESULTS

Center-aggregated data from 202,068 adult patients with T2D who received specialist care in 2021–2022 were extracted from 75 recruiting centers. Glomerular hyperfiltration was identified in 1262 (0.6%) patients. The prevalence of glomerular hyperfiltration ranged

widely across centers, from 0% to 3.4%, being similar in the different Italian macroareas ($p = 0.789$). Glomerular hyperfiltration prevalence of each center correlated negatively with mean age ($r = -0.309$, $p = 0.007$) and body mass index (BMI; $r = -0.395$, $p = 0.001$), and positively with the mean patient HbA_{1c} ($r = 0.353$, $p = 0.002$) and LDL-c ($r = 0.255$, $p = 0.030$) (Figure 1), while there was no correlation with center size ($r = -0.156$, $p = 0.182$) or either systolic ($r = 0.133$, $p = 0.254$) or diastolic ($r = 0.095$, $p = 0.417$) blood pressure.

The aggregated patient characteristics of 19 centers ($n = 41{,}761$ patients) with high glomerular hyperfiltration prevalence (>0.8%) were compared with 56 centers ($n = 160{,}307$ patients) with low-normal prevalence (Table 1). On average, patients in high-prevalence centers were younger, with lower BMI, and shorter diabetes duration. However, they had a worse cardiovascular risk profile, with higher HbA_{1c} and LDL-cholesterol, lower HDL-cholesterol, and higher prevalence of male sex, uncontrolled hypertension, and albuminuria. Glucose-lowering therapy was similar between groups, except for insulin being more frequently used in high-prevalence centers.

In multivariable analysis, age (st.$\beta = -0.318$, $p = 0.004$) and HbA_{1c} (st.$\beta = 0.301$, $p = 0.020$) were identified as the main determinants of glomerular hyperfiltration prevalence, while male sex (st.$\beta = -0.155$, $p = 0.135$), BMI (st.$\beta = -0.198$, $p = 0.051$), systolic blood pressure (st.$\beta = -0.016$, $p = 0.859$), LDL-c (st.$\beta = -0.034$, $p = 0.738$), and albuminuria (st.$\beta = -0.031$, $p = 0.737$) had no significant effects (model $R^2 = 0.326$). When added to the model, the prevalence of long diabetes duration showed a negative effect on glomerular hyperfiltration prevalence, which did not reach statistical significance (st.$\beta = -0.206$, $p = 0.060$), while treatment with SGLT-2 inhibitors had a neutral effect (st.$\beta = 0.070$, $p = 0.351$).

4 | DISCUSSION

We assessed the prevalence of unequivocal glomerular hyperfiltration and its associated risk factors in a contemporary cohort of 202,068 adult patients with T2D representative of the general diabetes population receiving specialist care in Italy. Overall, the prevalence of eGFR-defined glomerular hyperfiltration in this cohort was less than 1%, ranging from virtually 0% to 3.4%, whereas a high proportion of patients (~35%–50%) presented with suboptimal management of major metabolic risk factors, encompassing obesity,

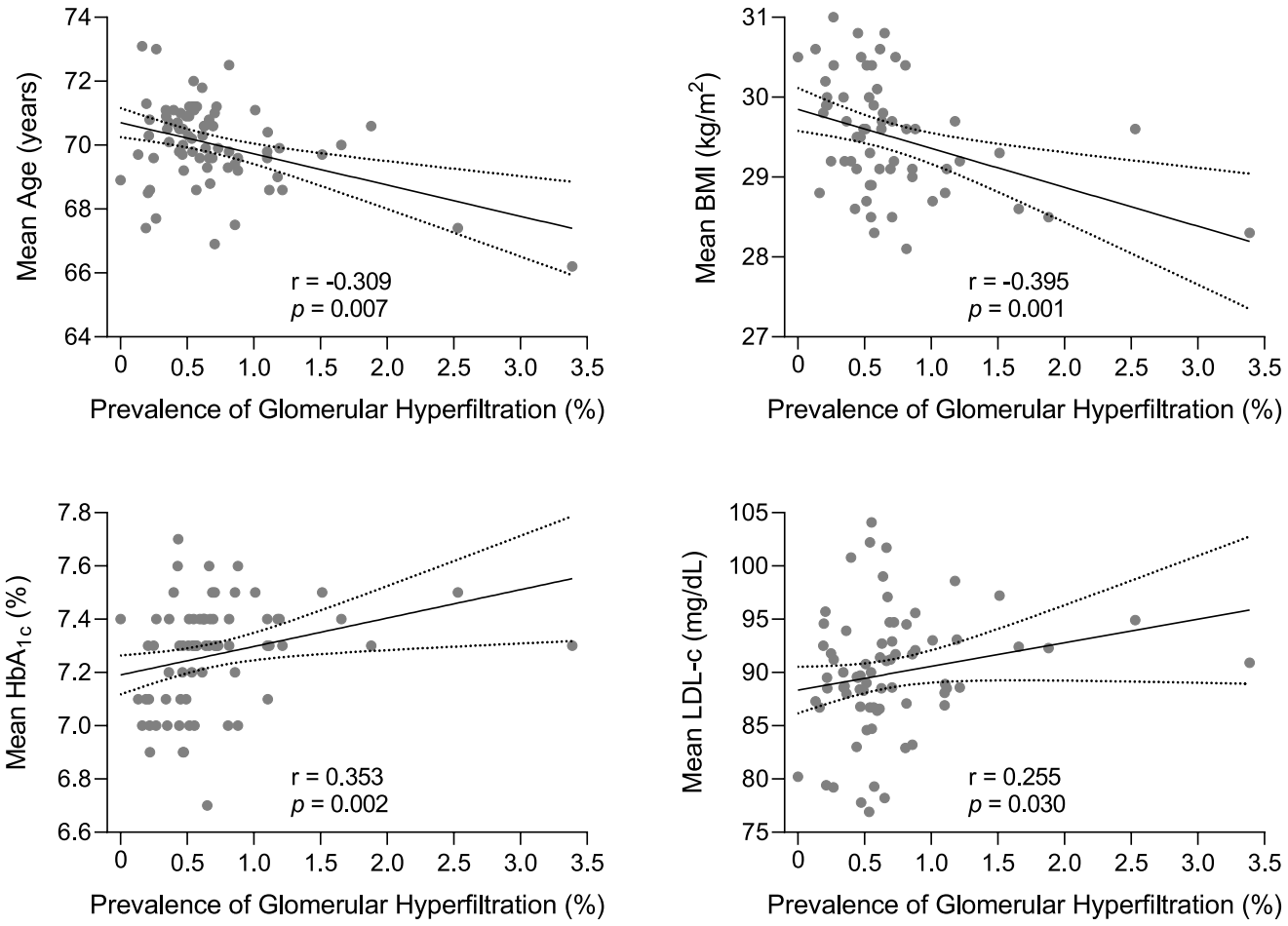

FIGURE 1 Relationships between the prevalence of glomerular hyperfiltration in each center and the mean patient age, BMI, glycated haemoglobin, and LDL cholesterol. Correlations were tested using the inverse-variance weighted Pearson correlation of aggregated center data. Best-fit lines and 95% confidence bands are shown. LDL, low-density lipoprotein.

TABLE 1 Characteristics of participating centers stratified by the prevalence of glomerular hyperfiltration.

	All centers	High prevalence	Low-normal prevalence	*p*
Centers, *n*	75	19	56	–
Patients, *n*	202,068	41,761	160,307	–
Patients per center, *n*	2694 ± 1762	2198 ± 1583	2863 ± 1801	0.136
Patients per macro-region, *n* (%)				0.535
North-West	66,283 (32.8)	15,027 (36.0)	51,256 (32.0)	
North-East	60,021 (29.7)	15,687 (37.5)	44,334 (27.7)	
Center	44,182 (21.9)	4875 (11.7)	39,307 (24.5)	
South	31,582 (15.6)	6172 (14.8)	25,410 (15.8)	
Age, years	70.1 ± 0.1	69.5 ± 0.1	70.2 ± 0.1	**0.045**
Age <55 years, %	9.5 ± 0.2	11.2 ± 0.4	9.1 ± 0.2	**<0.0001**
Sex (man), *n* (%)	57.6 ± 0.3	58.7 ± 0.6	57.3 ± 0.3	**0.043**
BMI, kg/m^2 [a]	29.4 ± 0.1	28.9 ± 0.1	29.6 ± 0.1	**0.001**
BMI >30 kg/m^2, %	39.1 ± 0.5	37.1 ± 0.6	40.0 ± 0.6	**0.002**
Tobacco smoking (active/previous), %	47.9 ± 0.6	48.1 ± 1.4	47.9 ± 0.7	0.919
HbA_{1c}, %	7.2 ± 0.02	7.3 ± 0.03	7.2 ± 0.03	**0.002**
HbA_{1c} > 7%, %	48.4 ± 0.8	52.8 ± 1.0	47.3 ± 0.9	**<0.0001**
Diabetes duration >5 years, %	75.9 ± 0.8	72.7 ± 1.8	76.8 ± 0.8	**0.037**
Systolic blood pressure, mmHg	134.8 ± 0.6	135.0 ± 1.3	134.7 ± 0.7	0.848
Diastolic blood pressure, mmHg	77.3 ± 0.2	77.8 ± 0.4	77.2 ± 0.2	0.234
Blood pressure >140/90 mmHg, %	49.9 ± 1.4	55.3 ± 2.9	48.4 ± 1.6	**0.038**
eGFR <30 mL/min/1.73 m^2, %	4.6 ± 0.1	4.5 ± 0.2	4.6 ± 0.1	0.758
Albuminuria, %	62.0 ± 1.4	68.3 ± 1.1	60.4 ± 1.7	**<0.0001**
Total cholesterol, mg/dL	164.5 ± 0.7	166.0 ± 1.1	164.0 ± 0.8	0.194
LDL cholesterol, mg/dL	89.0 ± 0.6	91.3 ± 0.9	88.2 ± 0.8	**0.033**
HDL cholesterol, mg/dL	48.5 ± 0.2	47.8 ± 0.1	48.8 ± 0.1	**0.020**
Triglycerides, mg/dL	139.1 ± 0.8	139.7 ± 1.9	138.8 ± 0.9	0.635
LDL >100 mg/dL, %	34.1 ± 0.7	35.7 ± 1.2	33.8 ± 0.8	0.178
Metformin, %	71.7 ± 0.5	71.8 ± 0.7	71.7 ± 0.6	0.902
Sulfonylureas/glinides, %	10.5 ± 0.8	11.3 ± 1.1	10.3 ± 1.0	0.512
Acarbose, %	1.0 ± 0.1	1.1 ± 0.3	1.0 ± 0.1	0.765
Thiazolidinediones, %	4.1 ± 0.4	3.4 ± 0.8	4.3 ± 0.4	0.347
DPP-IV inhibitors, %	22.0 ± 0.6	21.1 ± 0.8	22.3 ± 0.7	0.252
GLP-1 receptor agonists, %	22.3 ± 0.7	23.8 ± 1.0	22.0 ± 0.9	0.156
SGLT-2 inhibitors, %	21.7 ± 0.8	23.2 ± 1.4	21.4 ± 0.9	0.263
Insulin, %	33.9 ± 0.8	37.6 ± 1.7	32.9 ± 0.8	**0.013**
Any anti-hypertensive treatment, %	66.6 ± 1.0	65.7 ± 1.8	66.8 ± 1.2	0.617

Note: Continuous variables are reported as mean ± SE of inverse-variance weighted aggregated center data. Categorical variables are reported as mean ± SE of individual center proportions (%) weighted using the individual center size. Group differences were tested by Student's *t* tests weighted by inverse variance or center size as appropriate. Statistically-significant group differences are reported in bold.

Abbreviations: DPP-IV, dipeptidyl peptidase 4; LDL, low-density lipoprotein.

[a]Reliable data available in 15/19 (79%) and 48/56 (86%) centers.

poor glycaemic control, uncontrolled hypertension, and dyslipidemia. The high variability in glomerular hyperfiltration prevalence between centers could be largely attributed to wide differences in mean age and HbA_{1c}, while statistically significant group differences in sex distribution, BMI, blood pressure, lipid profile, and albuminuria played a minor role.

To our knowledge, this is the largest study to date evaluating the prevalence and risk factors for glomerular hyperfiltration in adults with T2D. Compared with previous observations,[10] the lower prevalence of glomerular hyperfiltration herein reported herein can be attributed to several reasons, including (1) use of a higher diagnostic cut-off point; (2) older patients' age; (3) improved care; and (4) more advanced disease stage. Several cut-off points of GFR have been proposed to define glomerular hyperfiltration due to the lack of consensus on diagnostic criteria and assessment tools.[11] In 15,773 Italian patients with T2D from the Renal Insufficiency And Cardiovascular Events study,[8] an eGFR of >104 mL/min/1.73 m^2 characterised the highest decile of eGFR distribution, used to define glomerular hyperfiltration. However, the reported prevalence of glomerular hyperfiltration in that study fell to 0.3% when a more stringent eGFR cut point was used (130 mL/min/1.73 m^2), and remained below 5% using age- or age- and sex-adjusted eGFR thresholds. Although there is a general agreement that an eGFR above 120 mL/min/1.73 m^2 identifies an inappropriately high GFR across all ages,[13,14] this threshold may be excessively conservative in the elderly,[5] considering a physiological ~1 mL/min/1.73 m^2 GFR decline per year after 40–50 years of age. A lower prevalence of glomerular hyperfiltration than older studies can also be explained by improved management of metabolic risk factors and widespread implementation of renin-angiotensin-aldosterone system (RAAS) inhibitors[15–17] and SGLT-2 inhibitors.[18–20] Finally, clinical data were retrieved from secondary and tertiary referral centers for the treatment of diabetes. Therefore, most patients enrolled in this study presented with long disease duration and may have already passed the initial stage of diabetes nephropathy characterised by glomerular hyperfiltration.

Our findings provide support to the potential pathogenetic role of several components of the metabolic syndrome as determinants of glomerular hyperfiltration, especially poor glucose control, and confirm the association between this condition and advanced kidney damage marked by albuminuria.[2] Nonetheless, the negative correlation between BMI and glomerular hyperfiltration prevalence was unexpected based on current physiopathological knowledge and should be interpreted with caution, requiring further confirmation.

Some limitations of this study should be acknowledged, mostly inherent to its retrospective design and ecological nature. First, the available data allowed the definition of glomerular hyperfiltration only based on a fixed eGFR threshold, which may be too stringent considering important age- and sex-related differences in GFR, as well as the known limitations of eGFR in detecting high directly-measured GFR values.[5] Second, aggregated center data did not allow for patient-level analyses, which would be informative in risk factor assessment. Third, data were automatically extracted from electronic clinical records, which are prone to errors and reporting bias. This may explain some unreliable BMI data, which were excluded from analyses, as well as inappropriately high rates of albuminuria compared with previous studies.[8] Fourth, detailed information about pharmacological therapy beyond glucose-lowering medications was not available; therefore, we could not examine the influence of RAAS inhibitors, diuretics, or nephrotoxic drugs on glomerular hyperfiltration.

In summary, eGFR-defined glomerular hyperfiltration was identified in a small proportion (0.6%) of a large contemporary cohort of Italian patients with T2D receiving specialist diabetes care. The prevalence of glomerular hyperfiltration increased with suboptimal control of metabolic risk factors, which would require improved management to meet therapeutic targets. Raising clinical awareness on this overlooked condition would be valuable to prompt careful evaluation and adequate treatment in individuals known to be at high risk of kidney and cardiovascular disease.

AUTHOR CONTRIBUTIONS

Domenico Tricò: Study design, data analysis, figure preparation, manuscript drafting. Gian Paolo Fadini: Data collection, manuscript editing and critical revision. Mario Luca Morieri, Riccardo Candido, Olga Eugenia Disoteo, Simona Frontoni: Data collection, manuscript editing. Anna Solini: Study design, data collection, manuscript editing and final revision; the study supervision.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there is no duality of interest associated with their contribution to this manuscript.

ETHICS STATEMENT

According to the Italian Medicines Agency det. 20/03/2008 on retrospective observational studies on anonymous data, preemptive approval by an ethics committee was not mandatory and the need for informed consent was waived given that aggregated center data were automatically collected and cannot be referred to specific individuals. The study was conducted in accordance with the 1964 Declaration of Helsinki and its later amendments.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

CONSENT FOR PUBLICATION

All the material in this manuscript is owned by the authors, who had reviewed the manuscript prior to submission and provided written

consent for publication. The results, tables and figures in this manuscript have not been published elsewhere.

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PEER REVIEW

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